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Team from Boeing/Cray Sweeps the Second Gordon Bell Award

Accepting the 1988 Gordon Bell Award from Mrs. Bell *(center)* are team members *(left to right)* John Lewis, Phuong Vu, Roger Grimes, and Horst Simon. The researchers were honored for their implementation of a general sparse matrix factorization on a Cray Y-MP supercomputer.

For "their superior effort in practical parallel-processing research," a team of researchers from Boeing Computer Services (BCS) and Cray Research, Inc. has won the second annual Gordon Bell Award. Mrs. Gordon Bell, director of the Boston Computer Museum, presented the award to the researchers on March 1, 1989, during the IEEE Computer Society's CompCon '89 in San Francisco.

The members of the winning team are Phuong Vu (Cray Research), Horst Simon (BCS at NASA Ames), Cleve Ashcraft (now at Yale University), Roger Grimes (BCS), John Lewis (BCS), and Barry Peyton (now at Oak Ridge National Laboratory). They were recognized for achieving a performance level of 1.56 gigaflops in their implementation of a general sparse matrix factorization on an eight-processor Cray Y-MP.

Gordon Bell, a vice president at Ardent Computer and former assistant director for computer science and engineering at the National Science Foundation, established the award in 1987 to demonstrate his personal commitment to parallel processing. As described in the July 1987 issue of *IEEE Software*, which administers the competition, the prize would consist of two $1,000 awards to be given essor of the same system). One award was to be for a program run on a general-purpose computer system of over $10 million and the other for a program run on any system.

The rules for the 1988 competition required that a submitted program run "faster than any other comparable engineering or scientific application."

In their submission to the competition, the BCS/Cray team demonstrated that the performance level of their program is considerably higher than that of any other general sparse matrix factorization routine currently in use. In addition, by using the code to solve the statics problem for some large-scale finite element models, including the shuttle rocket booster and the bulkhead of a Boeing 767 airframe, they had demonstrated that it can be used to solve real-world problems. The statics problem requires the solution of the sparse system of linear equations for the load vectors, given the finite element stiffness matrix and the force vectors.

Sparse Matrix Computations on Vector Supercomputers

The award-winning work grew out of the need to analyze very large scale finite element models in structural engineering both accurately and with a rapid turnaround. Large-scale finite element models have always been very demanding computational problems, with supercomputer requirements. Several sparse matrix algorithms account for the bulk of the work in these applications. These very kernels, however, did not perform well on early supercomputers, such as the Cray 1, since they required indirect addressing, which did not vectorize.

The situation improved with the introduction of the Cray X-MP and similar later-generation supercomputers, which provide hardware gather/scatter and access indirectly addressed data at vector speeds. A benchmark involving the dynamic analysis of a reactor containment building carried out at Boeing in 1986 showed that the availability of hardware gather/scatter cut the execution time for this application in half and improved the computational rate to nearly 30 megaflops. This rate, however, was five times slower than the performance levels of highly vectorized dense linear algebra routines. Sparse matrix computations, and as a consequence structural analysis applications, were not realizing the full power of vector supercomputers.

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Hoffman to Succeed Sward as Executive Director of MSEB

Marcia Sward, who has been executive director of the Mathematical Sciences Education Board since its inception in 1985, will be leaving MSEB in August to become executive director of the Mathematical Association of America.

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with the goals it set out for itself in 1985, with the most recent product of its efforts being the report *Everybody Counts*, done jointly with the Board on Mathematical Sciences and the Committee on Mathematical Sciences in the Year 2000."

Sward is no stranger to the administration of

Gordon Bell Award,

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A Supernodal General Sparse Solver

It was this lack of highly vectorized sparse matrix algorithms that motivated the early stages of the research that eventually led to the winning program. The original ideas for the work date back to a research project conducted in 1985 and 1986 at BCS, with partial funding from the Air Force Office of Scientific Research and the High Performance Scientific Computing Program at BCS.

The researchers—Ashcraft, Grimes, Lewis, Simon, and Peyton—who were investigating new algorithmic approaches to the solution of large-scale structural analysis problems, developed the key idea in discussions with Stanley Eisenstat of Yale University. They had observed empirically in the course of the sparse elimination process that the sparsity patterns of several columns of the matrix became identical as a result of the propagation of fill-in. Columns with identical patterns, they found, could be grouped in a supernode and eliminated simultaneously in vector mode. One of the resulting elimination processes is called supernodal general sparse elimination.

Since the supernodal approach led to a reduction in memory traffic, and a more highly vectorizable organization of the computation based on matrix vector multiplies, the supernodal factorization performed well on vector computers like the X-MP. In 1987 a supernodal experimental code developed by Peyton achieved 87 megaflops on the X-MP, with reduced storage and computational overheads.

Cray Research, to help satisfy its users' requirements for such software, contracted with BCS to develop a production-quality supernodal general sparse solver targeted for the X-MP. The development effort, performed by Grimes and Peyton and supported by Vu (from Cray), was completed in early 1988. The code has been used since 1988 on X-MP systems for actual production work. Further fine-tuning of the code resulted in single-processor factorization performance of close to 160 megaflops. On replacement of two critical kernels with assembly language versions, the rate increased to almost 190 megaflops.

A version of the code was ported by Vu and Simon to the Cray Y-MPs at Mendota Heights and in the Numerical Aerodynamic Simulation project at the NASA Ames Research Center in the fall of 1988. In the initial performance tests on the Y-MP, the code executed at more than 200 megaflops. The code, which is of medium length and contains a variety of integer computation and indirect addressing loops, was also an ideal candidate for evaluating the parallel processing capabilities of the Y-MP and the new autotasking software from Cray Research.

Autotasking alone, however, was not able to uncover the parallelism in the code. The key to further speedups and to the efficient utilization of the eight processors involved replacing the sparse matrix vector multiply routines with a strip-mining approach. Vu and Simon's collaboration resulted in an autotasked version of the code, which reached a level of 1.56 gigaflops. Further refinements and improvements since December 1988 have resulted in a speed of 1.68 gigaflops.

The actual performance level of 1.68 gigaflops is significant in several respects. The NAS project at the NASA Ames Research Center set out to deliver a rate of 1 gigaflops on a production supercomputer system. The results demonstrate that the goal of a sustained 1 gigaflops for a real application has indeed been accomplished with the Cray Y-MP. The fact that this performance was achieved on a traditional vector supercomputer, and not on one of the more massively parallel supercomputers, probably indicates that a Cray-style approach will remain dominant in high-performance computing for some time.

Finally, the history of this work shows that progress in parallel computing is almost always a collaborative effort, involving researchers with different backgrounds from research laboratories, universities, and industry.

Roger Grimes of Boeing Computer Services and Horst Simon of BCS and NASA Ames contributed to this article.

Venice-1 Symposium on Applied and Industrial Mathematics

Island of San Servolo
Venice, Italy
October 2-6, 1989

Official carrier: ALITALIA

For further information, see the SIAM Co-sponsored Conferences section of the Calendar (page 22).

Scientific Computing Approach,

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pices of the HPSC program and through contracts with governmental and industrial firms.

Working in the Applied Mathematics Unit of the SCA Division, under the direction of James Phillips, are 38 mathematicians (29 of them PhDs). Work done in the unit ranges from numerical analysis to electromagnetic analysis and optimal control. Current projects include enhancements to the GMRES algorithm for the iterative solution of nonlinear equations arising in a transonic application code, continued investigations in the area of constrained multivariate data fitting, analysis of an acoustics problem in airplane cabin interiors, and use of Bayesian classifiers in naval ship identification. About 80% of the mathematical work is done in support of Boeing, with the remaining 20% coming from government and commercial research and development contracts.

The HPSC program sponsors work in parallel computation that is carried out in the Applied Mathematics Unit. The research that led to the 1988 Gordon Bell Award was conducted jointly by members of the unit, Horst Simon of BCS (and NASA Ames), and Phong Vu of Cray Research.

The environment for scientific computing at BCS is strengthened by the symbiotic relationship between the HPSC program and the SCA division. While the work leading to the Bell award was not performed under the HPSC program, for example, early investigations of approaches to the parallelizing of unstructured sparse matrix algorithms had been performed under the program. This scientific computing environment is continuing to evolve as a result of an ongoing Boeing corporate initiative examining the role of computational modeling at Boeing: what it is, what it could be, and what it ought to be. Both the SCA division and the HPSC program are heavily involved in the development of this initiative.